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論　文　要　旨　（博士）

論文題目	コールドスプレーによる機能性皮膜創製と粒子堆積メカニズム

（要旨　1,200 字程度）

表面処理技術の一つであるコールドスプレー(CS)は，熱影響の少ない厚膜形成プロセスで，耐食被覆や部分補修など産業界への幅広い適用が期待されているが，実用化の例は少ない．その理由の一つとして，成膜メカニズムに未だ不明な点が多いことが挙げられる．成膜メカニズムの解明が進み，CS 適用性に関する一般則が確立できれば，CS プロセスの実用化推進に大きく貢献できるものと考える．そこで本研究では，CS を適用した新規アプリケーションの開発と実用化推進を目的に，合金・複合材料からなる各種機能性皮膜の膜質や粒子付着機構などについて検討し，皮膜の実用性を評価するとともに，CS 適用性に関するしきい条件を導出した．

耐食被覆用の Ni 基合金インコネル 625 皮膜では，基材の硬さによって付着機構が異なることが明らかとなり，成膜後の熱処理が密着強度の改善に有効であることがわかった．また，耐食性は溶射膜に比べて優れることを確認した．伝熱部材用 Cu-Cr 皮膜では，その成膜効率や付着機構には原料粉の表面酸化状態，粒度分布，および単粒子形態が影響することがわかった．また，熱処理によって溶製材並みの熱的特性を実現できる可能性を確認した．耐食被覆用 Ti 皮膜では，成膜後の熱処理および加圧処理が皮膜の緻密化に有効で，耐食皮膜としての適用可能性を確認した．この他，導電性付与 Cu 皮膜，耐摩耗 Al 系皮膜，電池部材用 Pb 皮膜の付着機構を明らかにするとともに，それぞれの実用化を図る上での開発指針を抽出した．

以上の結果を基に，皮膜の形成が可能となるのは，基材上の付着粒子においてメタルジェット形成または冶金的結合のいずれかが生じた場合であることが明らかとなった．この付着形態・機構には原料粉末および基材の材料物性が深く関与する点に着目し，それらの相関について整理した．その結果，粒子の付着機構には原料粉末の形態が影響し，凝集粉では衝突力を緩和して粒子の密着性や皮膜密度が低下するため，CS プロセスに用いる原料粉末形態は単一粉が望ましいとの指針を明らかにした．また，他の影響因子として①粒子と基材の機械的特性，②粒子の熱的特性，および③粒子の熱力学的特性が考えられ，これらの材料物性を用いて，成膜の可否並びにメタルジェット形成の有無を予測できるしきい条件式を導出した．このしきい式は，衝突界面において金属新生面どうしの接触や断熱せん断変形が起こりやすいことが成膜可能となる条件であることを表している．

以上，本研究では，CS プロセスによって得られた数種の機能性皮膜の実用可能性を確認するとともに，CS プロセスで成膜可能となる粒子-基材の条件を，材料物性をパラメータとしたしきい式で表した．得られたしきい式は，CS プロセスにおける成膜性や得られる膜質の予測を可能とするもので，CS 適用範囲の拡大や新規アプリケーションの開発に資するものと考える．

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A b s t r a c t

Title	Fabrication of Functional Coatings by Cold Spraying and Mechanism of Particle Deposition

(800 words)

Cold spraying (CS) is one of the surface treatment techniques, which has many advantages such as lower oxidation, lower pores, and lower residual stress, and hence thicker coating. When cold spraying is applied to fabricate coatings for corrosion resistance, local repair and so on, some industrial advantages will be expected. However, there are few examples of the practical use. One of the reasons about it is existence of many unidentified points on the fabrication of the coatings. Therefore, it is worth to reveal the mechanism and to clarify the threshold conditions on the CS applicability, in order to promote the practical use of CS process. The objective of this study is to develop the new CS applications and to promote its practical use. In this study, I manufactured several functional coatings made of alloys or composite materials, and evaluated properties of the coatings and adhesion mechanism of the feedstock particles. In addition, I evaluated the ability of the coatings for practical use, and clarified the threshold conditions on CS applicability.

Regarding Ni-based In-625 alloy coatings for corrosion resistance, it was revealed that the adhesion mechanism of the particles was reliant on hardness of the substrate, and the post-heat treatment was effective for improvement of adhesion strength of the coatings. Furthermore, it was confirmed that the corrosion resistance was superior to thermal sprayed In-625 coating. Regarding Cu-Cr coatings for heat transfer parts, it turned out that the influence factors on deposition efficiency of the coatings were surface oxidation of Cr particles, size distribution of the feedstock powders, and composite morphology of single-particles. Also, the feasibility of the thermal properties competing with that of casted Cu-Cr alloy by the post-heat treatment was confirmed. Regarding Ti coatings for corrosion resistance, it was revealed that the post-heat treatment and the compression were effective for densification of the coatings, and the applicability as the corrosion resistance coating was confirmed. Over and above this, the adhesion mechanism with regard to Cu coating for conductivity addition, Al-based coating for wear resistance, and Pb coating for battery parts were clarified respectively, and their applicability and requirements on practical use were confirmed.

From the results of evaluation of particle-adhesion mechanism on several functional coatings mentioned above, it was clarified that coating fabrication could be possible when either jetting or metallurgical bonding of the particles occurred. Since it should be noted that the material properties of the feedstock powders and the substrates extremely affect on the adhesion morphology and mechanism of the coatings, the correlation of them were investigated. As a result, the powder geometry influenced its adhesion mechanism. Namely, in the case of using agglomerated particles, relaxation of the impact force which caused decrease of adhesion strength of the coatings occurred easily due to their deformation during the collision. It implies that the agglomerated particles are not suitable for feedstock powders on CS process. Moreover, it was considered that the other influence factors on the adhesion mechanism were 1) Mechanical properties of particle and substrate, 2) Thermal properties of particle, 3) Thermodynamic properties of particles. And, the threshold equations using parameters of these factors on jetting and coating ability were defined. These equations mean that the coatings are formed when the contact between metallic new phases or the adiabatic shear deformation occurred.

In this study, the applicability for practical use of several functional coatings formed with CS process was confirmed. In addition, the materials conditions for fabrication of coatings were expressed by the threshold equations using material properties as parameters. These results are useful for development and expansion of CS applications, since these threshold equations enable us to estimate the forming ability or the characteristics of cold-sprayed coatings.